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Mesh Optimization for Grid-Based Hex Meshes

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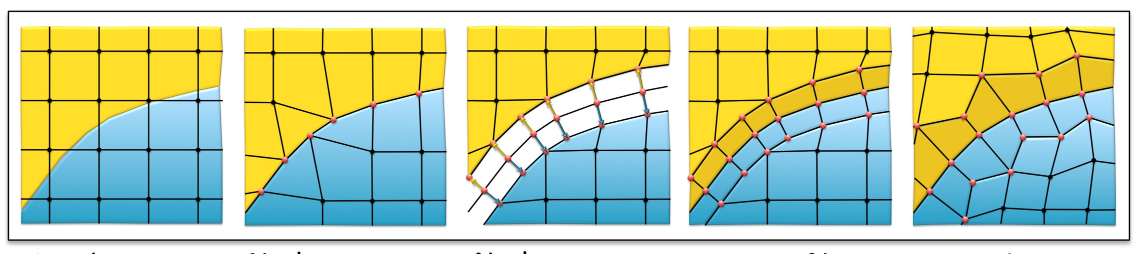
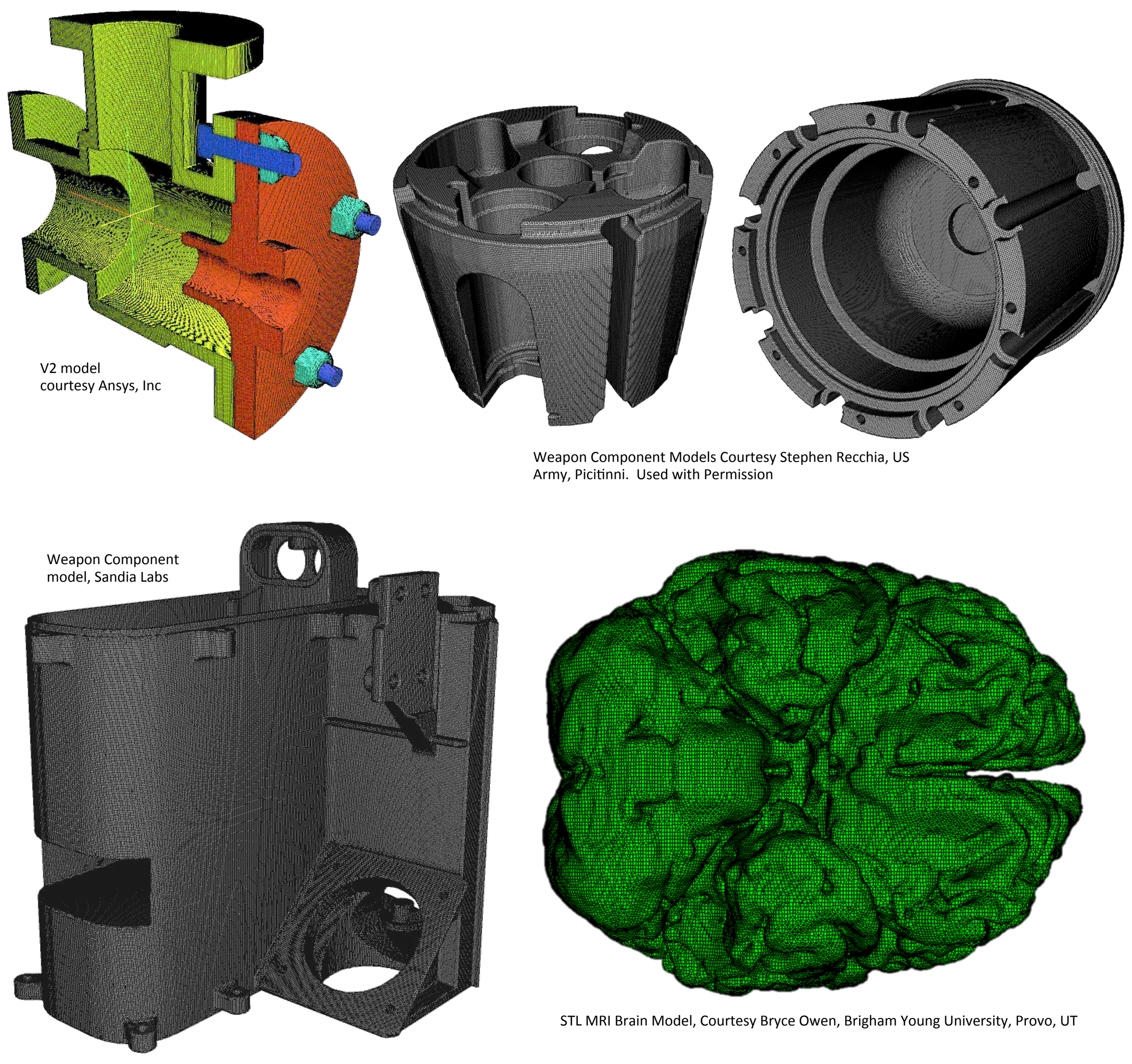
Mesh Optimization in Sculpt

Mesh Optimization is critical to grid based hex meshing tools such as Sandia's Sculpt tool. Work was accomplished this year (FY15) to improve overall success of Sculpt by dramatically increasing minimum mesh quality through a new procedure for parallel smoothing. It incorporates Laplacian and Optimization smoothing but adds damping and parallel coloring to achieve improved results.

Sculpt Meshing Procedure

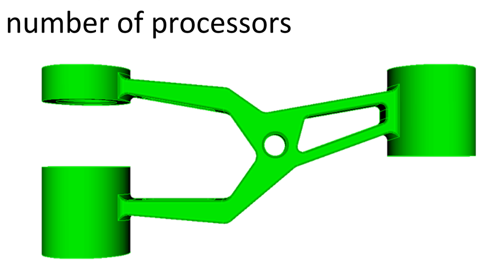


Overlay Cartesian Grid on Geometry | Nodes projected to interfaces | Nodes duplicated at interfaces and moved orthogonally | Layers of hexes created at interfaces | Smoothing performed

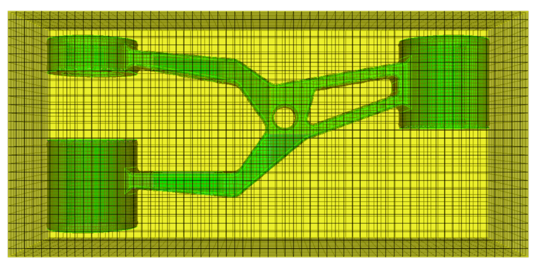


Parallel Meshing in Sculpt

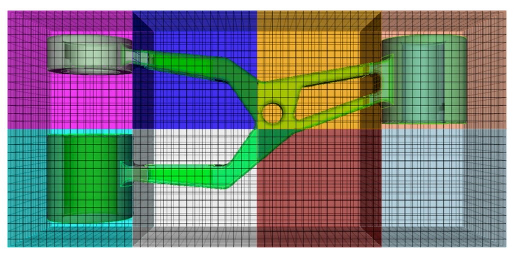
An overlay Cartesian grid is distributed among processors and a hex mesh is independently generated on each processor for a subset of the Cartesian domain. MPI is used for communication between neighboring processors to ensure continuity across processor boundaries. The same mesh will be generated regardless of the number of processors



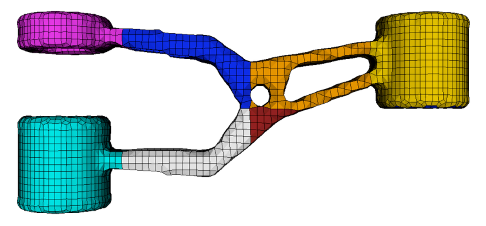
CAD geometry



Global overlay Cartesian grid



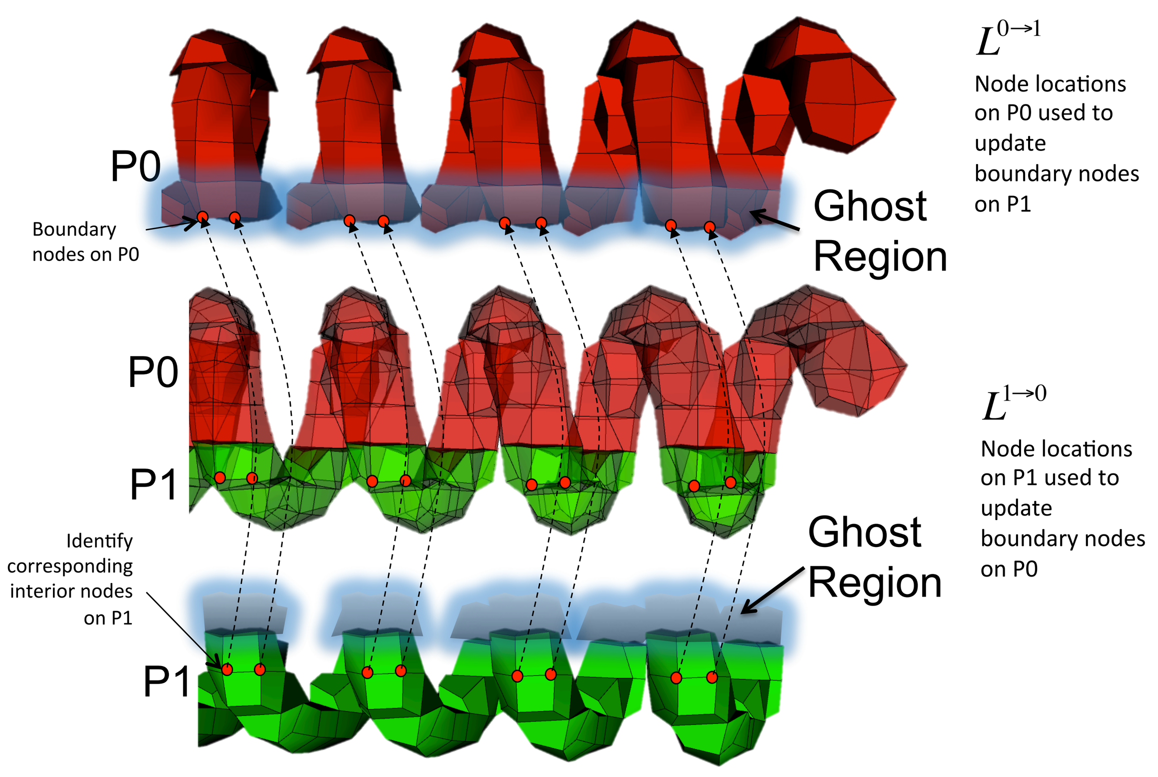
Cartesian grid decomposed and distributed amongst many processors



Each processor independently meshes its portion of Cartesian grid

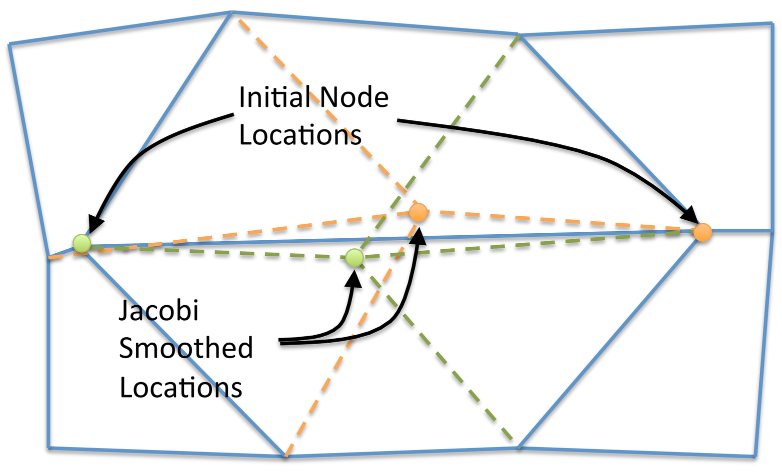
Parallel Smoothing

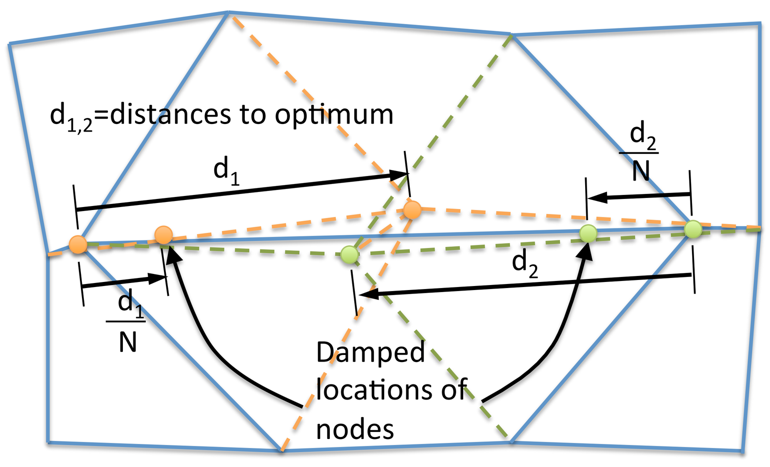
Ghosted elements and nodes are established and used to facilitate efficient MPI communication following each Jacobi iteration.



Damping

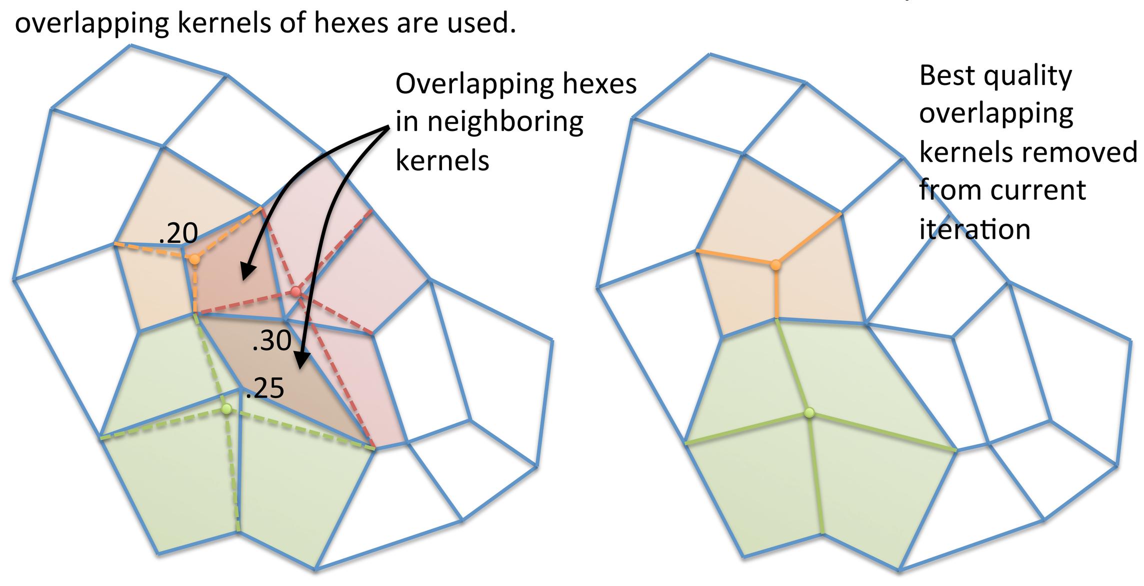
With Jacobi optimization smoothing it is common to get inverted elements following one or two iterations that are normally resolved with additional iterations. However there are cases that can oscillate and not allow for improvement. Smooth damping is employed to slow convergence avoiding inversions.



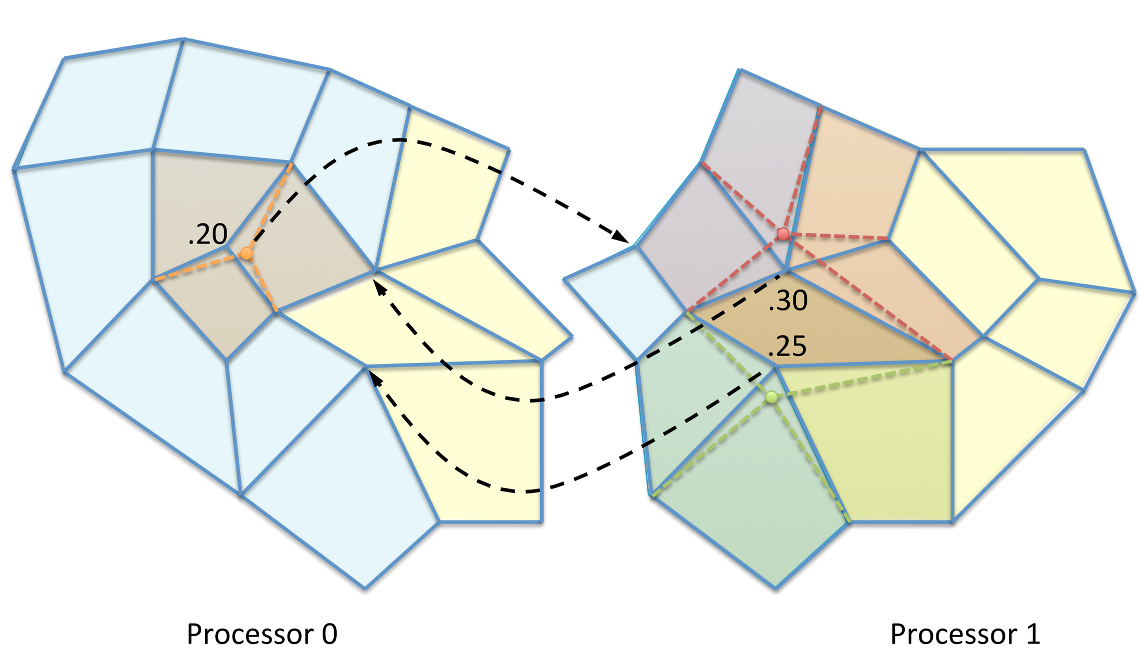


Parallel Coloring

The coloring algorithm will attempt to isolate kernels of hexes surrounding a node so that kernels do not overlap. Selection of kernels is ordered based upon minimum scaled Jacobian at the node. For each Jacobi iteration only non-overlapping kernels of hexes are used.



For parallel, master nodes must communicate with their ghosted (slave) nodes the minimum scaled Jacobian of their surrounding hexes. This ensures each processor consistently selects the same hex kernels for smoothing.

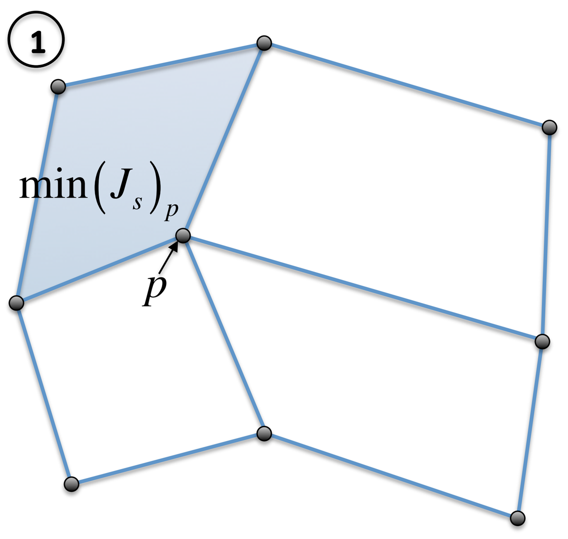


MPI communication of min Scaled Jacobian at node between neighbor processors

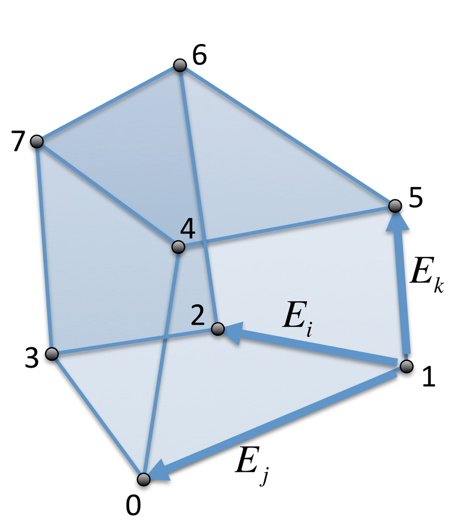
Node Optimization

A combined Laplacian and Optimization smoothing procedure is used. Following a fixed number of Laplacian iterations, Optimization is run until a minimum Scaled Jacobian is achieved.

1.



Compute minimum scaled Jacobian, $(J_s)_p$ of node p in all attached hexes

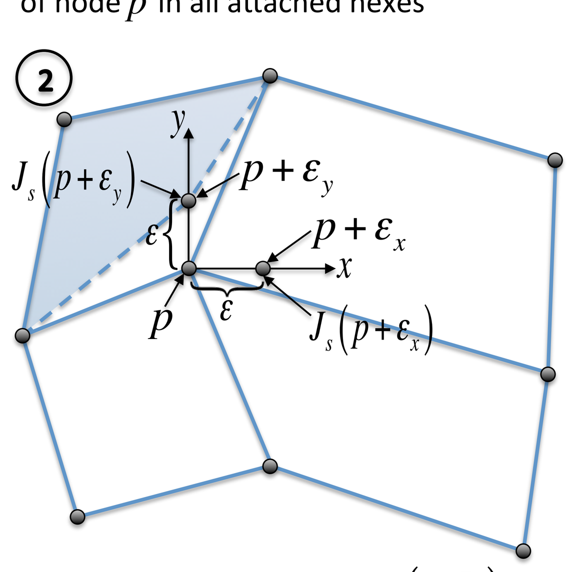


$$(J_s)_I = det\left\{\hat{E}_i\hat{E}_j\hat{E}_k\right\}^\top$$

$$J_s = min\left((J_s)_I, I = 0,1,\ldots 7\right)$$

Scaled Jacobian Definition

2.



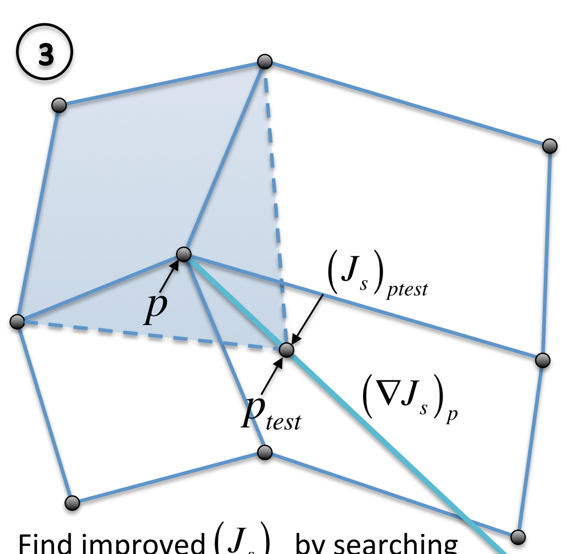
Compute numerical gradient $(\nabla J_s)_p$

$$(\nabla J_s)_{py} = \left\{\frac{J_s(p+\varepsilon_y) - J_s(p)}{\varepsilon}\right\}$$

$$(\nabla J_s)_{px} = \left\{\frac{J_s(p+\varepsilon_x) - J_s(p)}{\varepsilon}\right\}$$

Numerical Gradient

3.



Find improved $(J_s)_p$ by searching along vector $(\nabla J_s)_p$

The standard scaled Jacobian definition is modified to account for a target element size

S_t = Target element size

$$(J_s)_I = S_f det\left\{\hat{E}_i\hat{E}_j\hat{E}_k\right\}^\top$$

$$S_f = \begin{cases} e_s \le S_t, & \frac{e_s}{S_t} \\ e_s > S_t, & \frac{S_t}{e_s} \end{cases}$$

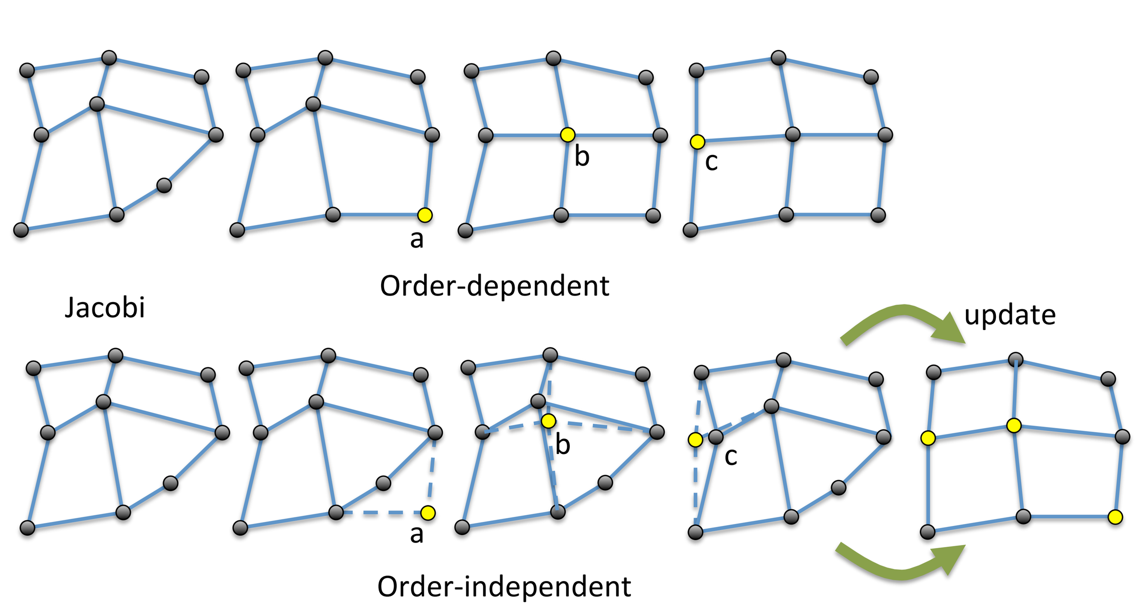
$$e_s = min(\|E_i\|, \|E_j\|, \|E_k\|)$$

4.

Procedure repeated until minimum J_s exceeds 0.2 or maximum iterations reached.

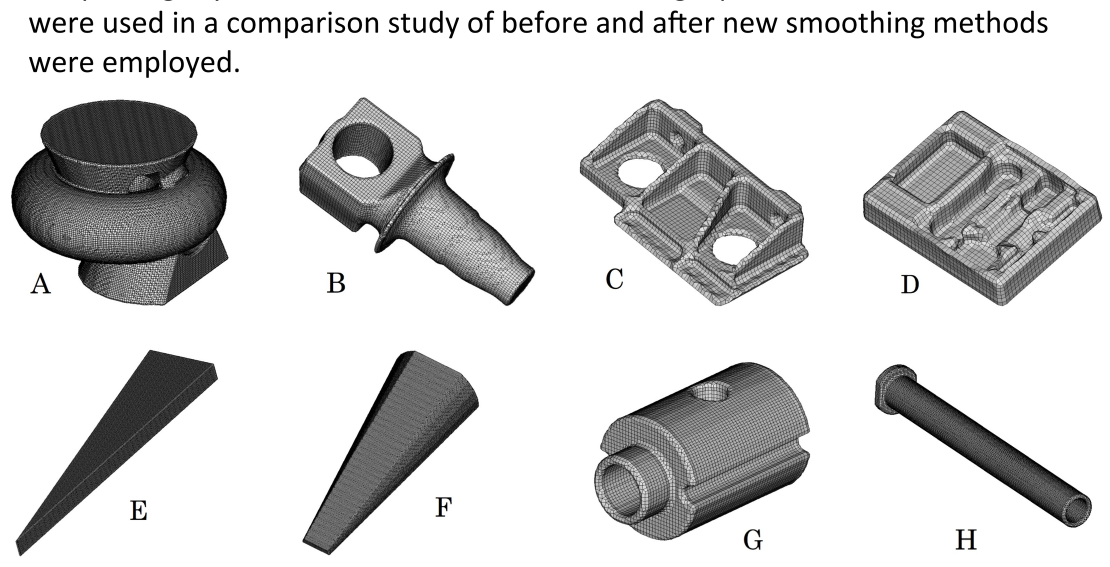
Smoothing Strategies

For serial applications, where order of operations is normally not important, a Gauss-Siedel approach is used. In order to maintain parallel consistency we use a Jacobi-based smoothing procedure.



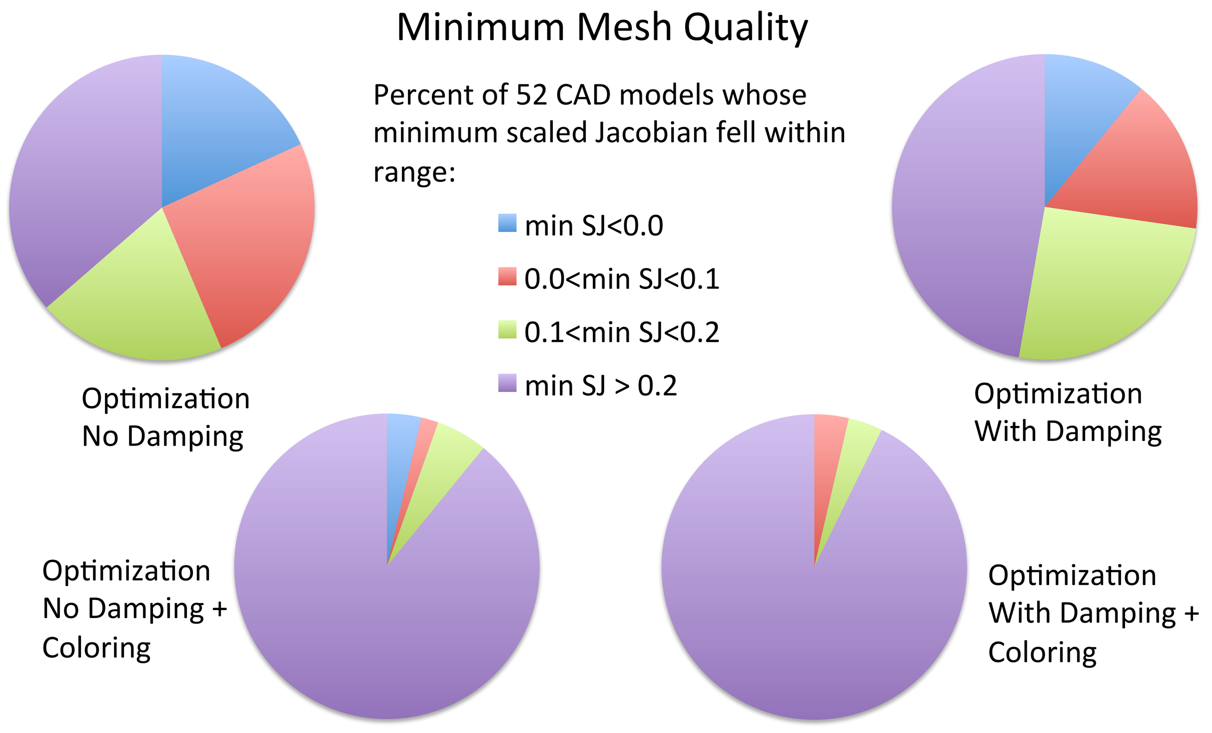
Sculpt Smoothing Comparison

Sculpt's nightly test sweet includes a set of 52 single part CAD models. These were used in a comparison study of before and after new smoothing methods were employed.

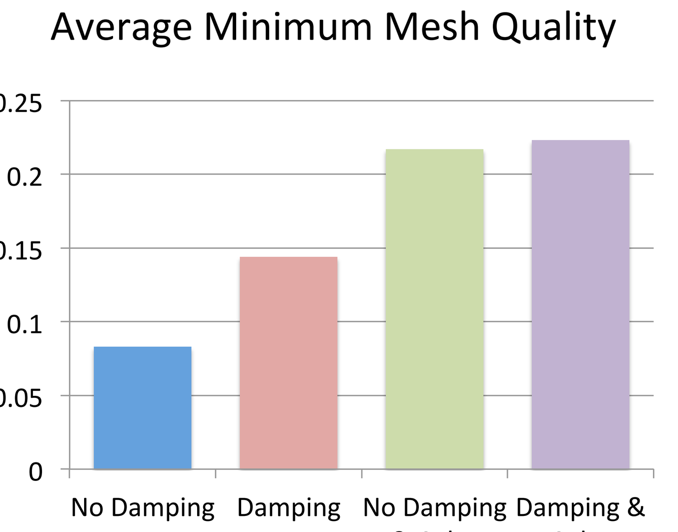


Examples of Test Suite Models: 52 Single Part CAD Models

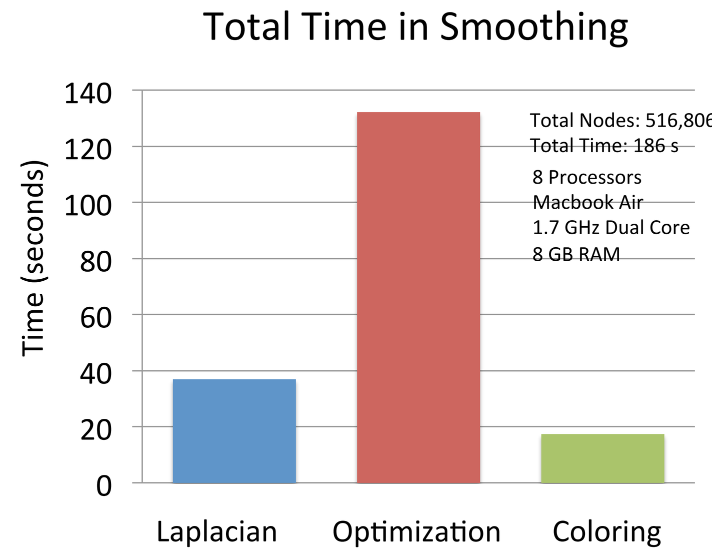
Minimum Mesh Quality



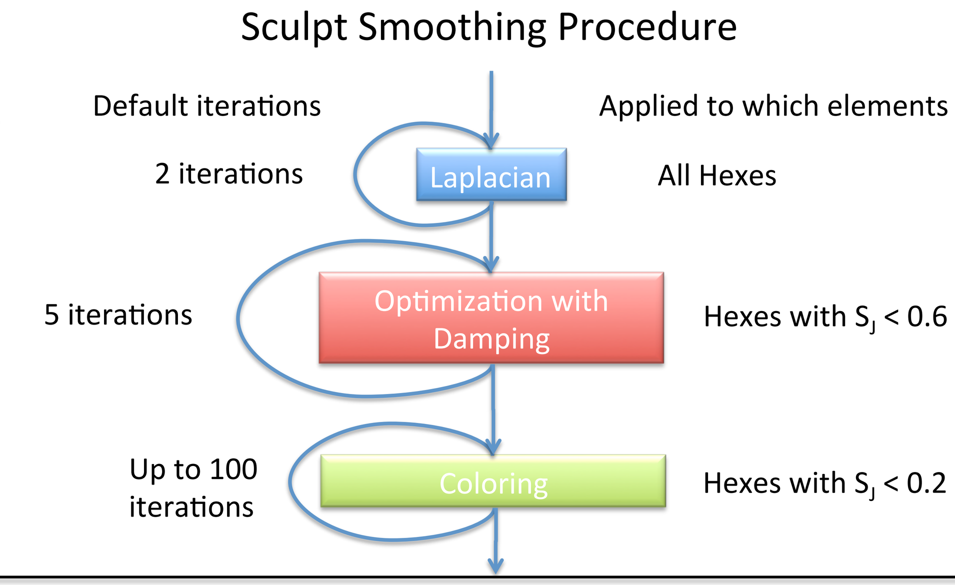
Average Minimum Mesh Quality



Total Time in Smoothing



Sculpt Smoothing Procedure



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